Using unmanned aerial vehicles and GPS receivers

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Global Positioning Satellite System

A Novel Long-term Method for Monitoring Global Warming

A small fleet of UAV aircraft could monitor the rise of pressure surfaces caused by the hypothesized rise in average temperature of the troposphere due to global warming.

UAVs would be programmed to fly immediately above the tropopause, and use GPS receivers to measure the aircraft's geometric altitude. By combining geometric altitude, local air pressure, and remotely-sensed vertical temperature profiles, it is possible to determine the geometric altitude of specific pressure surfaces.

The aircraft would fly during a twenty-year period over flight tracks that sample regions of predicted maximum and minimum global warming. Global Circulation Models (GCMs) predict that during the monitoring period some regions should warm approximately 2 K more than others, which would cause pressure surfaces in the warmer region to be uplifted 70 meters in relation to surfaces in the cooler region. From these measurements it should be possible to validate and refine global warming models which should eventually lead to improved global warming predictions.

Background

Radiosondes are sparse in many regions, especially polar and ocean areas, where abnormal global warming is predicted to occur. Area-averaging and the establishment of regional differences are thus dependent on a marginally adequate distribution of radiosondes.

Global warming models predict that increased CO_2 should produce a warming of the troposphere and a cooling of the stratosphere. Satellite temperature measurements are a blend of tropospheric and stratospheric temperatures, so part of the global warming signature is masked by an uncertain amount of stratospheric cooling. Satellites are also limited for the task of measuring global warming by their need to transfer calibration from one satellite to the next, since no single satellite lasts long enough to accomplish a meaningful monitoring task by itself. Thus, there is still a need for measuring the average temperature of the troposphere, or any effect of this warming, with an accuracy that can be assured over long time-scales.

Measurement Concept

An air parcel expands as it warms. An entire atmosphere also expands as it warms.

Surface pressure is a measure of the weight of the overlying atmosphere, and will not change during a global warming. If it can be assumed that a region's average surface pressure will remain constant over year timescales, the location of upper level pressure surfaces can be used to monitor changes in the time-averaged temperature field between the surface and the upper altitude pressure surface.

We propose to fly an airplane at an altitude that is always slightly above the tropopause, and to measure both ambient pressure, geometric altitude, and the temperature profile for nearby altitudes. This will permit the precise calculation of the altitudes of specified pressure surfaces which can be used to monitor the long-term pressure surface "uplifting" caused by global warming.

Measurement Strategy

We propose using a small fleet of Unmanned Aerial Vehicles (UAVs) to fly continuously across carefully-selected ground-tracks for a period of two decades. To illustrate the role of carefully choosing flight tracks, consider flights that sample the region between Alaska and Spitzbergen, and from the North Pole to the equator via Florida. These paths would sample extremes in predicted regional warming, according to Global Circulation Model studies of global climate change due to CO_2 increases.

Geometric altitude will be measured, using the differential GPS technique, whenever a pair of pre-positioned ground receivers are able to observe the same GPS satellites used by the UAV. Postflight data analysis will be employed to determine GPS corrections and extend them to regions where the differential GPS technique is not possible.

A microwave temperature profiler (MTP) will measure "altitude temperature profiles," which will be needed for determining the precise altitude of nearby pressure surfaces. The temperature profiles will also be used to continuously adjust the UAV altitude so that it stays above the tropopause. This is important in reducing errors of calculated pressure surface altitude, and will also assure an optimal sampling of the entire troposphere.

Analysis of UAV data will be stratified by season as well as year and location, since GCM models predict strong dependencies on both variables. Patterns of warming (and cooling) will be compared with predictions of several GCM models. We would work with GCM modelers to expedite the comparisons and enable assumptions.

Global Warming "Signal"

Global models predict regional temperature differences that are greater than the global average warming effect. For example, Hansen, et al. (1988) predict a North Pole regional warming of 4 K (from 1958 to 2015) in contrast with <0 K at latitudes near the equator. Another study predicts a

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10 K difference between northern Canada and the Arctic Ocean between Greenland and Norway.

Three GCM models predict a large warming (produced by a doubling of CO_2) during winters in northern Canada, and one model predicts a mild warming (10 to 15 K versus 3 to 5 K). Thus, model differences are approximately 10 K during a six-decade period.

During the planned study period, it is estimated that differences for regional temperature are predicted to be approximately 2 K. Thus, during the study period, global warming effects are expected to move pressure surfaces in the "upper troposphere/lower stratosphere" in such a way that regional differences should be approximately 70 meters.

ERROR ANALYSIS

The altitude of nearby pressure surfaces can be measured with an accuracy that is estimated to be 19 meters on 15-second timescales. Assuming, conservatively, that measurement precision is only slightly less than its accuracy, regional averages will improve according to the square-root of time spent over the region.

For example, after traversing a Canada sized "region" in 20 hours, pressure surface altitudes will be measured with a precision of ≤27 cm. Three aircraft could traverse ten regions in three days. If the altitude of pressure surfaces could be measured with a precision of 26 cm every three days, regional *differences* could be measured with a precision of 38 inaccuracies. Presumably, these regional differences would be unaffected by instrument inaccuracies, provided accuracy biases changed slowly.

During the course of a decade monitoring program, the precision of regional seasonal differences in *trend* could be as low as "1 cm per decade." Since global warming models predict trends 3500 times greater than this, it is unlikely that measurement uncertainties will be important.

The above derivation does not allow for the presence of natural variations in pressure surface altitudes. It will be useful to consider two components of natural variations: stochastic and non-stochastic variations.

The stochastic component for global averages has a magnitude of approximately 0.11 K per year for each "region" (based on surface temperature data for the past 100 years). This leads to pressure surface altitude fluctuations of about 3.7 m. Regional fluctuations will be larger, and are estimated to be approximately 14 m each year, or 28 m each season.

After a decade of monitoring, these stochastic fluctuations will produce a noise on the measurement of "regional difference trend" of about 3 m/decade for each seasonal comparison. This is 10% of the "signal trend," and is therefore a concern. After two decades, this component of noise will be only 2.5% of the "signal trend."

The non-stochastic component of natural variations has longer periods and larger amplitudes. The two most important examples are volcanic eruptions and the El Niño Southern Oscillation, or ENSO.

Volcanic eruptions produce effects that have a characteristic decay time of about one or two years. The ENSO is quasi-periodic, with components between three and seven years. Their effect upon pressure surface altitude at tropopause altitudes is approximately 20 and 7 m, respectively.

We interpret work by others to indicate that these effects can be removed with residuals of approximately three or four m. This is comparable to the stochastic variations, so they should have the same impact on the measurement of a secular trend. In other words, both the stochastic and non-stochastic natural variations are likely to introduce uncertainties of approximately 10% of the predicted trend after one decade, and 2.5% of the predicted trend after two decades.

THE NEED FOR A CAREFULLY-DESIGNED STUDY

Given that the normal year-to-year regional fluctuations are the dominant source of uncertainty in measuring and assessing the effects of global warming, this proposal is designed to overcome the regional variability limitation by emphasizing the use of many regional/seasonal comparisons.

> *Potential tracks include round-trip flights between the Washingon, D. C. area and the North Pole, Washington and the Equator, and Alaska and Norway.*

A flight track that extends from the North Pole to the equator (via eastern Canada) includes the equivalent of five Canada-sized regions. The other hypothetical UAV flight track, from Alaska to Spitzbergen, will sample an equivalent number of regions. This hypothetical intercomparison of about ten such Canada-sized regions will provide a multitude of comparisons with model predictions. In this way it may be possible to overcome the inherent variability of regional average tropospheric temperature.

However, a more thorough evaluation of this analysis strategy is warranted, and should be conducted in conjunction with global warming modelers. This more careful study should identify which regional comparisons are most likely to lead to GCM model validations, since some regional changes may be dominated by specific model components which need refinement.

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